# A LIFECYCLE ASSESSMENT FRAMEWORK FOR EVALUATING THE REDUCTION OF CARBON DIOXIDE THROUGH INJECTION IN ACTIVE OR DEPLETED RESERVOIRS

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## Abstract

Several industries are conducting research to reduce their greenhouse gas (GHG) emissions because of the growing concerns over the GHG's effect on the atmosphere. In the petroleum industry, sequestration in active or depleted reservoirs seems a feasible solution towards lowering these emissions. Furthermore, injection in depleted reservoirs is said to offer important storage capacity, whereas injection in active reservoirs for enhanced oil recovery (EOR) combines GHG storage with the production of additional oil.

This paper presents a systematic approach to investigating and comparing the benefits of $CO_2$ storage in depleted versus EOR reservoirs. The benchmark is the potential for net $CO_2$ sequestration over the lifetime of the reservoir. An example applying a lifecycle assessment to an ARCO (now BP Amoco) project in West-Texas is described. The analysis on depleted reservoir storage is still in progress. However, preliminary results with EOR suggest GHG emissions from this power intensive process are small compared to the storage capacity of the formation, leading to a significant reduction of GHG emissions.

## Introduction

With the burning of fossil fuel, arise anthropogenic emissions of greenhouse gases which enhance the natural greenhouse effect and could contribute to changing global climates. The petroleum and power industries are considering projects to reduce their emissions. Solutions include the offset of emissions by reforestation and forest management projects, as well as the reduction in emissions through energy efficiency improvements at their facilities, and sequestration of greenhouse gases in the oceans or underground in aquifers or fossil fuel reservoirs.

Fossil fuel reservoirs are very attractive as storage for greenhouse gases (especially carbon dioxide) because of existing infrastructure and/or a good understanding of the reservoirs. Two types of reservoirs can be used for that purpose: depleted reservoirs and reservoirs still active where enhanced oil recovery (EOR) can be applied.

Depleted reservoirs have not been employed for the storage of carbon dioxide yet. However, for many years now, they have been an essential link in the supply chain to ensure uninterrupted availability of natural gas during periods of high-energy demand such as winter. When the demand is low and excess capacity occurs, natural gas is stored in depleted reservoirs. It is recovered later on when necessary. In 1997, there were at least 410 underground reservoirs in the United States used for natural gas storage, with a total working gas capacity of 108 billion cubic meters (Thompson, 1997). Depleted reservoirs are located throughout the U.S. All areas of the United States with known oil and gas reservoirs also have depleted reservoirs. Both depleted oil reservoirs and depleted gas reservoirs can be used for storage of carbon dioxide and it is estimated the storage potential for these formations is around 794 billion metric tonnes worldwide (Stevens and Taber, 1999). This is a large potential for storage compared to the 6.6 billion metric tonnes of greenhouse gases in carbon dioxide equivalent emitted by the U.S. in 1997 (adapted from EPA, 1999).

For the case of active reservoirs, enhanced oil recovery is initiated when pumping techniques no longer produce enough oil for the fields to remain economically attractive. Supercritical carbon dioxide ($CO_2$) is injected in the reservoir and serves as an efficient solvent by reducing the viscosity of the oil, and thus enabling the oil to flow more readily to the producing wells. The carbon dioxide usually originates from naturally occurring $CO_2$ reservoirs, and in some cases $CO_2$ comes from processing plants. Reservoirs suitable for EOR are mostly located in the Permian Basin, TX, but can also be found in Alaska, California, Kansas, Oklahoma and the Texas Panhandle (Moritis, 1998). The current production from $CO_2$ EOR accounts for about 30 thousand cubic meters of oil per day from a total of 63 projects, or about 3% of total U.S. oil production (Moritis, 2000). Typically, an average of 530 to 1750 cubic meters of $CO_2$ is injected per cubic meter of oil recovered (Beike and Holtz, 1996). The overall storage potential in EOR reservoirs is estimated to about 129 billion metric tonnes (Stevens and Taber, 1999). Therefore, reservoirs using $CO_2$ for enhanced oil recovery present the advantage of being able to store large quantities of $CO_2$ while providing the economic incentive of oil production.

This presentation will compare the two storage options (depleted reservoirs versus EOR reservoirs) following a life cycle assessment methodology. Based on a currently operated EOR reservoir in the Permian Basin, we will investigate the storage potential as well as the emissions generated by the energy intensive process which includes the injection of the $CO_2$, its separation, capture and compression. The EOR reservoir analysis reflects the actual data from the case study with $CO_2$ originating from natural reservoirs and from the recycled $CO_2$-rich stream of the processing plant (attached to the EOR process for the treatment of the produced gas stream). The depleted reservoir case is a virtual case, a modification of the same reservoir to fit a depleted situation.

## Methods –Life Cycle Assessment

To determine the environmental burden associated with the injection of $CO_2$ in active or depleted reservoirs, we chose to use a life cycle assessment (LCA) in order to capture the impacts from "cradle to grave." The LCA can be used for product/process comparison, pollution prevention or simply for understanding one process/product's impacts on the environment. An LCA's major strength is the objectivity of the environmental analysis, and the elimination of externalities in project management regarding environmental issues.

The LCA follows a very structured methodology. We focused our efforts here on the inventory analysis and the impact analysis. Simply, the process is broken down into small entities, therefore facilitating the determination of input streams (resource requirement) and output streams (emissions) for each entity. The impact analysis provides a quantitative or qualitative characterization of the streams into and out of the system.

This presentation will be limited to greenhouse gas emissions and to the boundary of the facility. The scope of this work includes the extraction of oil/gas from the reservoir, the processing of the gas phase (extraction and separation of the usual components such as $CO_2$, $H_2S$, natural gas liquids), compression of the separated $CO_2$ stream, and underground injection in the reservoir either for use in EOR or simply for long term storage. Because we are investigating an existing reservoir under EOR, the study will be limited to the estimated 40-year lifetime of the reservoir.

A functional throughput unit was selected as a normalizing factor in order to allow for comparison among alternative approaches. In the case of EOR, and other methods of oil production in general, the net quantity of crude oil produced is the valued commodity. Therefore, releases to the environment and resources needed throughout the processes are quantified and indexed to the quantity of crude oil produced by the facility.

This LCA analysis uses specific site data for field emissions and storage as well as for electricity generation. The data used to determine the emissions are in part from direct sampling, and in part estimates based on applicable emission factors (E&P Forum, 1994; EPA, 1998; AP-42, 1998; IPCC, 1996). To remain conservative, the results presented below rely mainly on the E&P Forum emission factors or the EPA emission factors when no corresponding E&P Forum emission factors were available. The storage capacity is determined by performing a mass balance on the amount of $CO_2$ injected and the amount of $CO_2$ produced along with the oil.

## Results and Discussion

A significant part of a life cycle assessment has to do with resource utilization or the use of natural resources to perform the process or obtain the desired product. Resources include both the natural resources used directly by on-site devices and indirect resources for generation of the grid power used by the facility. In our example, the resources consist of gas and coal, but remain regional variables and would be different for other part of the US. For the oil recovery process linked to enhanced oil recovery the resources also include $CO_2$. This paper is not going to discuss this aspect in order to better focus on emissions and storage.

The greenhouse gases emitted by the EOR processing can be divided into the direct and indirect emissions. Indirect emissions are attributable to electricity generated outside of the facility boundaries and transported through the grid to power equipment within the system investigated. In our case study, we found indirect emissions account for 13.5% of total $CO_2$ emissions, about 0.1% of $CH_4$ emissions, and approximately 0.8% of $N_2O$ emissions.

Direct emissions originate from the use of on-site equipment fired by natural gas. On-site fired equipment demands more power than equipment receiving electricity from the grid and therefore emissions are higher. Direct emissions account for 59.2% of $CO_2$ emissions, approximately 2% of methane emissions, and 84.1% of $N_2O$ emissions.

The rest of the on-site emissions are accounted for by process equipment leakage and routine maintenance that could result in fugitive methane emissions. In addition, flaring associated with the separation plant is also included and constitutes the remaining of the emissions presented. The system's total $CO_2$ emissions amounted to 0.3 kg / kg of oil produced. The EOR process also emitted 0.0015 kg of methane / kg of oil produced, and 2.1 $10^{-5}$ kg of $N_2O$ / kg of oil produced.

Simultaneously, the process contributed to storing 3 kg of $CO_2$ / kg of oil produced, and 0.18 kg of methane / kg of oil produced. Table 1 provides a summary of the emissions from the EOR process per kg of crude oil produced. The mass balance for carbon dioxide exhibits process emissions as positive quantities, while the amount stored in the reservoir is shown as a negative number. This highlights the $CO_2$ storage potential of an oil reservoir.

**Table 1** Mass balance of greenhouse gas emission for the EOR process (kg / kg of oil produced)

| | Carbon Dioxide | | Methane | | Nitrous Oxide | |
|---|---|---|---|---|---|---|
| | On-site | Off-site | On-site | Off-site | On-site | Off-site |
| Emission | 0.31 | 0.05 | 0.002 | 1.5 x$10^{-6}$ | 2 x$10^{-5}$ | 1.6 x$10^{-7}$ |
| Storage | 3 | | 0.2 | | | |
| Balance | -2.6 | | -0.2 | | 2 x$10^{-5}$ | |

Our results suggest the EOR process using $CO_2$ as a solvent contributed to limiting the amount of greenhouse gases reaching the atmosphere over the lifetime of the reservoir (40 years). This table includes both the $CO_2$ recycled and the $CO_2$ originating from natural reservoirs. Only the recycled $CO_2$ would have been vented under normal EOR operations. Close to 45% of the $CO_2$ injected in the reservoir over the 40 year period came from the recycling plant. We found that all of the $CO_2$ recycled is ultimately stored in the formation and 20% of the $CO_2$ purchased from natural $CO_2$ reservoirs is stored again in the EOR reservoir.

The part of the analysis related to storage of carbon dioxide in depleted reservoirs is still in progress. Therefore, we are unable to provide a comparison of both types of storage at this time, but will present the complete results of the study at the conference. However, we expect emissions for depleted reservoir storage to be in the same order of magnitude than for the EOR process. The depleted reservoir storage capacity should be significantly higher because EOR requires injection of additional fluids in the reservoir, like water, to boost production. Also injection in depleted reservoir is easier to monitor because nothing is actually removed from the reservoir.

## Conclusion

The first part of the analysis demonstrates the $CO_2$ storage potential of an oil reservoir in the Permian Basin, TX, through the use of enhanced oil recovery. Concurrent with the storage possibilities in an active reservoir, we estimated the greenhouse gas emissions originating from the range of equipment used and from flaring practices and fugitive emissions. The results suggest the EOR process is not only a major $CO_2$ user, but could also be a significant way to store the $CO_2$ underground. This study, so far, also illustrates that the overall sequestration efficiency could be enhanced by utilizing captured and recycled $CO_2$ from process vents and stack effluents, instead of using $CO_2$ from natural reservoirs.

The second part of the study on injection of $CO_2$ in depleted reservoirs will be presented at the conference. We will analyze and compare both storage options focusing on storage capacity and emissions associated with separation and compression of the $CO_2$ stream. Incentives might play a significant role in the implementation and widespread use of these storage options.

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